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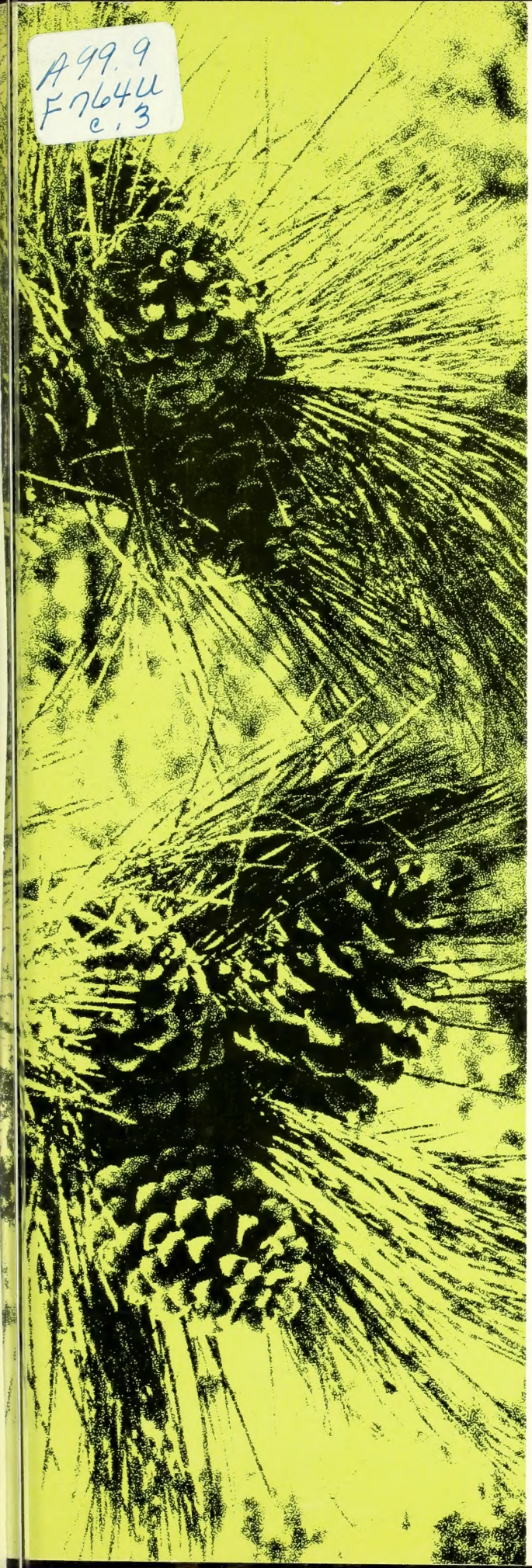

Regeneration of Ponderosa Pine in the Northern Rocky Mountain–Intermountain Region

Marvin W. Foiles
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USDA Forest Service
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Abstract

Present knowledge of natural and artificial regeneration of ponderosa pine in the northern Rocky Mountains and Intermountain West is summarized. In this territory, ponderosa pine grows under a wide range of climatic, edaphic, and topographic conditions. Summer drought is a major factor in regeneration; thorough site preparation is therefore necessary to reduce competition. Some regeneration techniques that have been tested in this territory are described. Planting is the most successful method of artificial regeneration; direct seeding is sometimes used. Several cutting methods may provide for natural regeneration if properly applied.

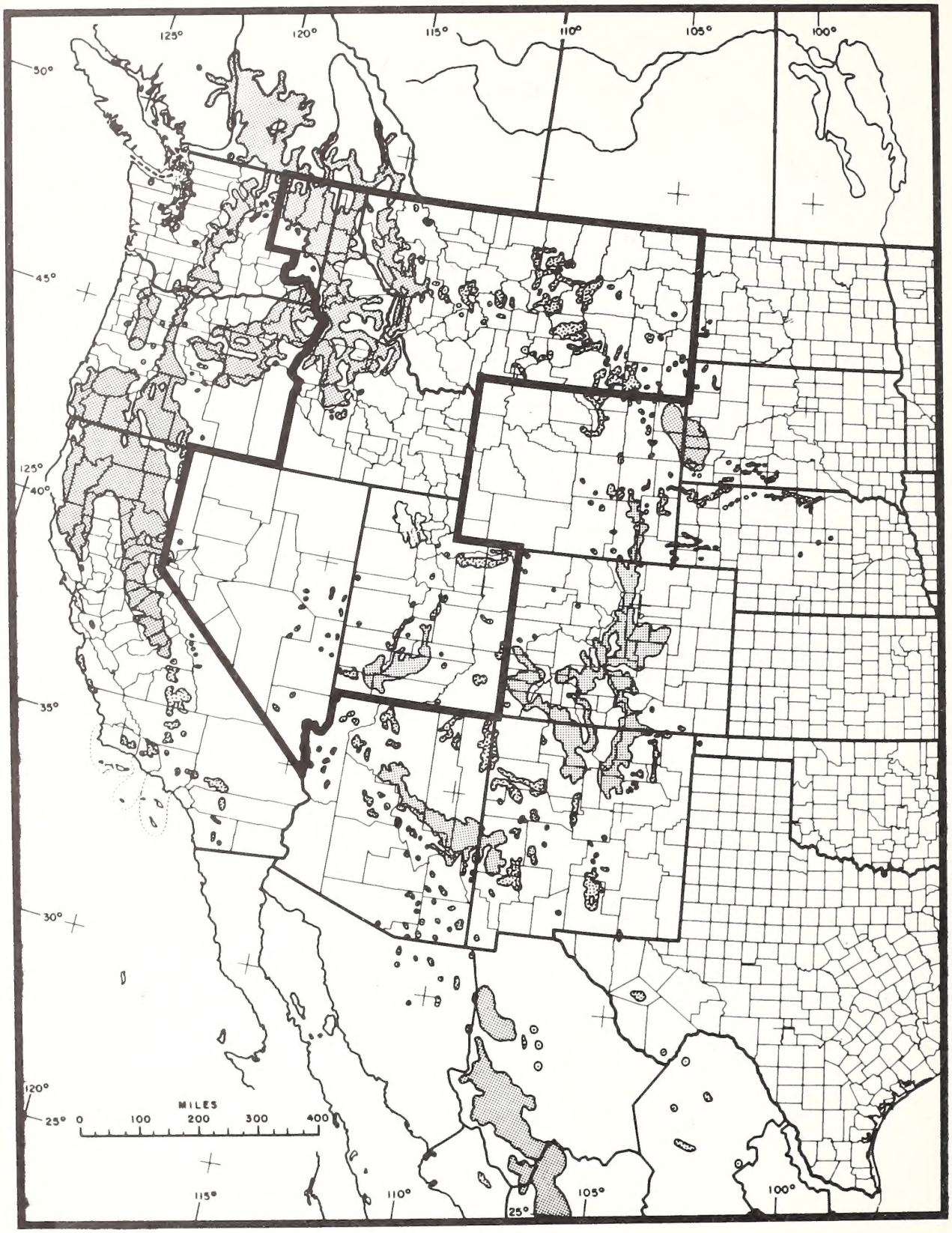

Figure 1.--The northern Rocky Mountain-Intermountain region, outlined with a heavy line, in relation to the total range of ponderosa pine.

Introduction

To reproduce, or regenerate, a forest is to remove the old stand and establish a new one. The term "regeneration," considered now as the result rather than the process, denotes an aggregate of tree seedlings 4.5 feet or less in height that have originated from natural or artificial seeding, outplanted nursery-grown seedlings, or transplanted native stock. More briefly, regeneration consists of groups of trees 4.5 feet or less in height, regardless of origin.

Successful and dependable forest regeneration requires the employment of skills from many disciplines. The overall objective is the early establishment of a new stand adequately stocked with desirable species at a reasonable cost. The specific manner of achieving that objective is determined by the management plan for each unit. Some forests are managed for a single use or primarily for one dominant use such as recreation, watershed management, timber production, or range for wildlife and livestock. Most forest land is managed for multiple use to obtain the greatest total benefit from a combination of uses. Regeneration measures for each of the above uses may be different, and management for multiple use is likely to require compromises. For example, if timber production is the dominant use, regeneration efforts may include techniques that expose considerable bare soil to hasten the establishment and growth of the new stands. If esthetic values and watershed protection are additional concerns, however, large expanses of bare soil may be undesirable.

Protection of the site is always an important consideration in regeneration. When soils are erosible, slopes are steep, and the land is valuable as watershed, it is obviously essential to establish desirable vegetation quickly on cleared sites. The ground must be prepared for regeneration in a way that will protect the site from erosion. For example, grass seed may be sown on logged sites to protect the site until tree seedlings are planted after suitable site preparation.

Specific management goals in a regeneration program are the time schedule and the species and stocking desired in the new stand. Like the overall objective, these are determined by management priorities. Once the species has been chosen, however, its requirements become limiting factors in decisionmaking.

The wide diversity of conditions under which ponderosa pine (*Pinus ponderosa* Laws.) grows makes a single prescription for regeneration impossible. Techniques must differ according to the locality and the type of area to be regenerated, as, for example, timber sales, recent burns, or brushfields (old burned areas). On this basis, the choice between natural and artificial regeneration must be made, and an appropriate method of site preparation chosen. Where cutting is yet to be done, the regeneration plan should precede the design of the cutting.

Ponderosa pine is the most widely distributed pine in North America, extending from the Fraser River in British Columbia to west central Mexico and from northeastern Nebraska to the Pacific Coast (Curtis and Lynch 1965). This paper reviews methods of regenerating ponderosa pine in only one geographic region within its vast range in the United States (fig. 1). The research and observations reported here span a period of some 50 years within an area generally known as the northern Rocky Mountain-Intermountain region, namely, extreme northeast Washington, Montana, Idaho, Nevada, and Utah. References to work elsewhere are made only when important findings help to evaluate regenerative procedures for use with ponderosa pine in this area.

Ponderosa Pine in the Northern Rocky Mountain-Intermountain Region

Climate and Soil of the Habitat

Ponderosa pine grows under a wide range of conditions typified by varying rainfall, high temperatures and low humidities during the growing season, mountainous topography, and great diversity of soil types and depth (Curtis and Lynch 1965).

Climate.--In typical ponderosa pine habitats, average annual temperatures vary from 40° F to 48° F and average annual precipitation from 12.7 to 26.8 inches (table 1). The average amount of precipitation from June through September depends on the locality. Idaho City, Idaho, for example, receives one-third more precipitation per year than Darby, Montana, but barely half as much during the June-September period. In southern Utah, the June rainfall is sparse but increases during the following 3 months, almost reversing the pattern of many other places.

In certain places, such as central Idaho, the June-through-August climate is severe. Forest temperature may be 110° F in the shade, relative humidity 3 percent, and total July and August precipitation as little as 0.02 inch.

Most sites are subject in the early or late growing season to soil moisture stress and high soil surface temperatures. Tree growth primarily depends on water stored in the soil from melted snow and from spring rains. Summer precipitation, whether light showers or high-intensity rainstorms, is probably of little use to tree seedlings because of interception, surface evaporation, and runoff. Soil moistures below the wilting point have been measured at a depth of 60 inches in the granitic soils of central Idaho. Soils on south aspects dried out and reached the wilting point sooner than on north aspects.[1]

Soil.--From northern Montana to southern Utah there is wide diversity of soil origins and hence soil types. Parent material includes quartzite, argillite, schist, basalt, andesite, granite, limestone, and sandstone. Probably the soils most subject to drought are the coarse-textured, highly erosible granitic types of central Idaho and southwestern Montana. The soils of western Montana on which ponderosa pine is found are the Gray Wooded Great Soil Group (Cox 1957). They are characteristically about 50 inches deep, with a pH of 6 and a "well-developed platy A_2 horizon, a blocky B_2 horizon with a distinct accumulation of clay, and overall gray appearance." The soils developed from argillites and quartzites tend to be shallow and coarse with low water-holding capacity. The medium-textured soils that develop on morainic materials are deeper and their moisture-holding capacity is higher.

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[1]Unpublished data, Div. Watershed Manage. Res., Intermt. For. & Range Exp. Stn.

Table 1.--*Average temperature and precipitation at selected localities in the ponderosa pine forests of the northern Rocky Mountains (U.S. Weather Bureau)*

Location	Average temperature					Average precipitation				
	June	July	Aug.	Sept.	Year	June	July	Aug.	Sept.	Year
	Degrees F					*Inches*				
Chewelah, Wash.	61	67	64	57	46	1.1	0.6	0.6	1.1	19.8
Spokane, Wash.	62	70	68	61	48	1.5	.4	.4	.8	17.2
Kalispell, Mont.	59	66	63	55	43	2.2	1.0	1.1	1.0	15.4
Missoula, Mont.	58	67	64	54	43	1.9	.8	.7	1.0	12.8
Darby, Mont.	57	65	63	55	45	1.9	.8	.8	1.2	15.7
Grangeville, Idaho	58	67	66	58	46	3.0	.9	.8	1.5	22.6
New Meadows, Idaho	56	63	60	53	41	2.0	.6	.6	1.2	25.3
Council, Idaho	63	73	70	62	48	1.8	.4	.4	.9	26.8
Idaho City, Idaho	58	67	65	57	45	1.4	.3	.3	.6	23.2
Bryce Canyon, Utah	59	63	60	48	40	([1])	1.1	2.9	3.4	12.7

[1]Less than 0.06 inch.

In the Intermountain Station territory there are extensive areas of shallow soil with bedrock often close to the surface. These are frequently intermingled with deeper soils on level plateaus and, more generally, on minor ridges and major drainage boundaries. The total acreage of shallow soils is not known, but surveys on two timber sale areas in central Idaho revealed that the proportion is considerable. On 480 acres on the Boise Basin Experimental Forest supporting ponderosa pine, soil was less than 24 inches deep in 23 percent of the area. On Zena Creek, a tributary of the South Fork of the Salmon River, Payette National Forest, a soil survey showed 31 percent of the area to have soils only 8 to 16 inches deep on bedrock.[2]

Most commonly, the south and west aspects support shallower soils than the north and east aspects. Soil depth generally decreases, regardless of aspect, toward the top of ridges. The deeper soils occur in the ravine bottoms where the topography tends to be gentle, although exceptions occur on some plateaus as in eastern Utah. Cox and others (1960) point out that in western Montana forest productivity is influenced principally by the depth of soil in which tree roots can develop.

Shallow soils affect silvicultural practices (Curtis 1961). For example, certain units may be eliminated from a proposed cutting because soil is not deep enough for adequate site preparation for regeneration or because the potential for erosion or site deterioration following cutting is too great.

[2]O. C. Olson. Soils of the Zena Creek logging study, Payette National Forest, Region 4 unpubl. ms., illus. 1960.

Ecological Position and Plant Associations

Ponderosa pine is the most drought tolerant of the major coniferous tree species in the Intermountain Station territory. Therefore, it occupies the relatively warm and dry lower slopes of the Rocky Mountains as they rise above the arid plains. In parts of the territory, such as southern Idaho, Montana, and Utah, open stands of the pinyon-juniper cover type form a transition zone between the prairies and forests in the mountains. In northern Idaho and eastern Washington, however, the boundary between ponderosa pine forests and prairie is abrupt.

In the lowest zone of forest, ponderosa pine is the climax, and the only coniferous species able to survive in that droughty climate. As ponderosa pine extends farther up the moisture-temperature gradient, it becomes a seral tree in stands where more competitive species eventually become climax.

Daubenmire and Daubenmire (1968) classified the forest vegetation of eastern Washington and northern Idaho into ecological units termed habitat types. Ponderosa pine occurs as a climax or seral species in 11 of their habitat types, listed below in approximate order from most warm and dry to most cool and moist.

Pinus ponderosa/Stipa comata
Pinus ponderosa/Agropyron spicatum
Pinus ponderosa/Festuca idahoensis
Pinus ponderosa/Purshia tridentata
Pinus ponderosa/Symphoricarpos albus
Pinus ponderosa/Physocarpus malvaceus
Pseudotsuga menziesii/Symphoricarpos albus
Pseudotsuga menziesii/Calamagrostis rubescens
Pseudotsuga menziesii/Calamagrostis rubescens, *Arctostaphylos* phase
Pseudotsuga menziesii/Physocarpus malvaceus
Abies grandis/Pachistima myrsinites

In the first six habitat types in the list, ponderosa pine is the climax dominant. In the last five types it may be a temporary invader following burning or logging, but it is replaced as the climax dominant by Douglas-fir or grand fir. Ponderosa pine grows rapidly where it is seral if light is sufficient. In an understory position, it cannot compete with the climax species and is eventually eliminated from the stand. In the past, wildfires were largely responsible for maintaining ponderosa pine in mixed stands by creating bare areas in which the pine could become established and compete favorably with the slower-growing climax species. In recent years, logging and burning of clearcut patches have created bare areas.

Ponderosa pine is rated very resistant to ground fire, second only to western larch among the coniferous species of the northern Rocky Mountains (Flint 1925). This rating applies to old trees with thick bark, but small trees are easily killed by ground fires.

Planning for Regeneration

In all regeneration planning, the basic choice lies between natural and artificial regeneration. With ponderosa pine, management objectives and the characteristics of the location and site determine this choice. With either method, however, site preparation is usually necessary for seed germination and seedling survival.

Natural Versus Artificial Regeneration

Both natural and artificial regeneration have evident advantages and disadvantages. Planting permits initial control of composition and stocking, a distinct advantage, but requires a considerable investment. When stands are to be clearcut and planted, logging is more straightforward than when seed trees must be retained on the cutting area. On planted areas there is no delay before regeneration begins and the chance of early success is more certain than if natural regeneration is relied on, although without good planning there is some danger of an inappropriate seed source.

Natural regeneration, though often economical, is less reliable, and the retained seed trees must be cut and removed after reproduction is established. The seed trees help to ameliorate a harsh climate, however, and are esthetically pleasing. The ultimate choice between artificial and natural regeneration will be decided by such local and specific factors as the presence and location of seed trees, amount of available seed, availability of planting stock raised from seed collected on the tract or nearby, size and topography of area, soil and site, silvical requirements of the species, condition of trees in the overstory, and costs.

With artificial regeneration of ponderosa pine, the time schedule for the reproduction period is easier to determine and is much shorter than with natural regeneration. Primarily, natural regeneration is limited by the occurrence of an adequate cone crop. Therefore, a time objective must be long enough to include a heavy seed year. A reasonable objective for natural regeneration would be one-tenth of the rotation or the occurrence of one adequate cone crop. If natural regeneration fails to become established in that time, the site should be planted. With careful planning for seed collection and nursery production a timber sale area can be planted within a year. A reasonable objective would be 5 years following the cutting.

Another limitation is the availability of seed from a proper seed source. In natural regeneration there is no problem, providing that desirable seed trees have been selected, because the seed comes from on or near the site. For direct seeding or planting, however, seed must be collected within genetically approved horizontal distances and elevations to ensure that the trees will be adaptable to the site.

Seedling survival is a key factor in regeneration in these mountainous regions because the cost of repeated treatments is high. If the initial attempt at either natural or artificial regeneration fails, rapid reinvasion of competing vegetation and steep slopes make the second effort difficult and the total investment in the new stands high.

Figure 2.--Because vegetation was not completely eliminated, competition has reinvaded this plot 1 year after stripping by bulldozer.

Site Preparation and Treatment

When regeneration, either natural or artificial, is to be established, some kind of site preparation is usually necessary, to remove competition and expose mineral soil. Evaporation is slower from mineral soil than from forest duff. The better moisture relations of mineral soil make it a better medium for pine seed germination and seedling survival (Roe and Squillace 1950).

Throughout the growing season, plants of all kinds draw moisture from varying depths of the soil. The wilting point is often exceeded at depths down to 2 feet in vegetated soils. In availability of moisture, the first year is the most critical period for the tree seedling. Upper soil layers dry quickly and first-year roots may not grow fast enough to reach lower moisture supplies. Although the vertical penetration of roots of 1-year natural ponderosa pine seedlings is known in extreme cases to reach 51 inches, they are found more commonly at the 16- to 20-inch depth (Curtis and Lynch 1965). The removal of competing vegetation makes moisture available for tree seedlings and increases the survival of natural regeneration and outplanted nursery stock (Foiles and Curtis 1965b; Curtis and Coonrod 1961).

On areas needing regeneration the competing vegetation may consist of grasses, sedges, forbs, and shrubs. Forest soils also contain seeds which germinate when the site has been disturbed (Curtis 1952). As many as 948,736 viable seeds per acre of forbs, grasses, sedges, and shrubs have been recovered from the topsoil in the ponderosa pine type of central Idaho (Krygier 1955). When the vegetation on a site is removed and the top few inches of soil are pushed aside there is less competition than if only the existing vegetation is removed. The thoroughness with which live vegetation and seed in the mineral soil are eliminated from a site will determine the rate of reinvasion from seed and from sprouting root systems (fig. 2). Removing part

of the topsoil from a large area would be incompatible with the aim of protecting the soil from erosion and preserving site productivity. Nevertheless, some soil can be moved from spots, strips, or trenches without seriously damaging the site. Probably the fibrous-rooted species of grasses, forbs, and sedges provide more competition (Spence 1937) than shrubs (Baker and Korstian 1931), if density of root systems and the depths to which they penetrate are criteria.

Rather drastic site preparation methods have been developed in recent years, out of the need to solve some of the problems of regenerating ponderosa pine stands. For example, attempts to plant ponderosa pine in central Idaho and Utah had failed for nearly 30 years before the Town Creek Planting Study was begun in 1954. Results from that study showed that thorough site preparation (bulldozer stripping), combined with careful planting, brought success. In the years following the Town Creek Study, the method of dozer stripping and planting was employed to reforest thousands of acres of land covered with brushfields resulting from wildfires. Without that treatment, those productive timber-growing sites would have remained unproductive for many years. Such drastic methods as dozer stripping or terracing are neither desirable nor necessary in all situations, however. They are discussed here to show their value where they are desirable.

The use of chemicals and fire has also been criticized and sometimes restricted in recent years because of the dangers of environmental pollution. Forest managers must weigh the advantages and disadvantages of these methods in relation to the overall management objectives for the forest. If chemicals or fire endanger high-priority values of the land, other methods of site preparation can be used. The method should be chosen long before the time arrives to prepare the site, because the choice may affect earlier management decisions, such as the selection of a cutting method.

Scalping and mulching.--On steep slopes where it is impossible for machinery to work safely and efficiently, ground must be prepared by hand, fire, or chemicals. In hand preparation, a pit (basin) or scalp can be formed on the sidehill (fig. 3). When a pit is made, the tree or seed is planted slightly to one side of the center to avoid being covered by soil sloughing from above. Scalps may vary in size according to the amount of competing vegetation but should be at least 30 inches in diameter.

Mulching, like scalping, has been used to preserve moisture by reducing evaporation from the soil and by limiting the growth of competing vegetation around planted trees. Straw, sheets of 4-mil black polyethylene, and mats of glass fiber 1/4-inch thick were applied to scalped spots 3 feet square on steep slopes in central Idaho to observe the benefits of mulches (fig. 4). Four tests over a 3-year period were indecisive in terms of survival of planted trees. Generally, seedlings on scalped and mulched spots survived no better than on spots that were only scalped (Hall 1971).

DeByle (1969) significantly increased survival of planted Jeffrey pine in Nevada by mulching with 3- by 3-foot sheets of 4-mil black polyethylene. His test was similar to the central Idaho experiment using the same material to mulch planted ponderosa pine. The contrasting results from these experiments indicate that the effectiveness of mulching cannot be generalized. More information is needed on the effects of mulches under different conditions.

Herbicides.--The reduction and elimination of vegetative competition by chemicals before planting have been frequently tested by foresters in recent years. Perhaps the most common use has been in brushfields where vegetation has invaded forest stands

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[3]Data on file at Intermt. For. & Range Exp. Stn., USDA For. Serv., Boise, Idaho.

Figure 3.--A shallow layer of soil was removed from this scalp to eliminate seeds as well as roots of competing vegetation.

Figure 4.--A glass fiber mulch 3 feet square is held in place by heavy wire pins and stones.

after uncontrolled fires (fig. 5). Both woody species and herbaceous species are found in brushfields; the species composition will vary by location. Because all plant species are not affected to the same degree when any one herbicide is applied, more than one chemical may be required. In central Idaho[3] satisfactory results have been obtained with aerial applications of 2,4,5-T and dalapon applied in 2 successive years at the rate of 8 gallons of spray per acre. Concentration dosages were 3 pounds acid equivalent (a.e.) of 2,4,5-T and 20 pounds of dalapon in 1 gallon of diesel oil and 6 gallons of water. Another area sprayed with 3 pounds a.e. of 2,4,5-T in 7.25 gallons of diesel oil produced satisfactory kill of shrub vegetation. Handspraying similar areas with more dilute solutions (4 pounds a.e. of 2,4,5-T and 20 pounds of dalapon in 200 gallons of water) gave equally good results. The solutions containing dalapon successfully reduced competition from grasses and sedges on the site.

Other herbicides have been used successfully on brush species in the northern Rockies (Potter 1968, Ryker 1966). New herbicides are being discovered and developed rapidly and will increase the flexibility and usefulness of chemical treatments. Foresters can use chemicals to prepare sites for regeneration, but they should choose the chemicals carefully and recognize their limitations. For example, herbicides that successfully kill growing vegetation may not kill plants that grow from seed in the soil after spraying. Chemical sterilants or preemergence phytocides may control germinating weed seeds, but residual chemical in the soil may be toxic to tree seedlings if they are planted too soon. Herbicides can be valuable tools if the right chemical is used according to tested procedures. Foresters need to be aware of current developments in order to make effective use of chemical site preparation.

Figure 5.--Aerial application of herbicides to a brushfield preparatory to planting has been found helpful. This field is in central Idaho.

Fire.--Burning is a common method of disposing of slash from logging operations. Slash may be piled, or burned where it fell. Disposal of slash and accumulated unmerchantable material makes the area more accessible to planting or seeding crews and usually reduces plant competition to a degree that allows planted trees to survive. Burned areas, however, are rapidly invaded by plants, either from seed in the soil or by sprouting from surviving root systems.

The seed of some species of forest shrubs such as *Ceanothus velutinus* have impermeable seed coats and remain dormant until exposed and warmed by fire. Therefore, fire can actually result in prolific germination of old seed stored in the soil (U.S. Forest Service 1948; Curtis 1952). As many as 72,745 viable *Ceanothus velutinus* seed per acre have been found in the top soil layer of the ponderosa pine type (Krygier 1955). A combination of fire and spraying with herbicides may be necessary to prepare such sites adequately for pine regeneration.

Mechanical techniques.--On gentle slopes, where machines can operate safely, mechanical site preparation can be efficient and economical (Gordon 1956; Curtis 1964). Toothed land-clearing blades (fig. 6), bulldozer blades, and disks, mounted on the front of tractors, as well as disks or plows mounted on the rear, have all been used successfully in Intermountain Station territory. On sale areas where clearcuts are made and slash is dozer-piled and burned, planting is sometimes successful without further site modification, although plowing in addition usually results in higher survival.

In brushfields, tractors with angle dozer blades can be used to prepare sites by stripping or terracing, depending on the steepness of slope. Stripping can be used on slopes of less than 40 percent gradient. By this technique, vegetation is pushed from a strip the width of the dozer blade. Angling the dozer blade removes only enough soil to eliminate the vegetation (fig. 7). To minimize the possible erosion hazard, the strips are made parallel to the slope contour, and a band of vegetated ground is left undisturbed as a barrier to soil movement between strips. Rows of trees are then planted in the prepared strips.

On slopes steeper than 40 percent gradient, tractors cannot safely traverse the slope and do the stripping unless a terrace is constructed. The degree to which such structures approach the level varies in actual practice. Sometimes a trail is constructed for the uphill track of the tractor only, and the surface of the terrace slopes down toward the outside. This type of construction is common in shallow, rocky soils where a deep cut may remove too much soil to retain a productive site. On other sites the terraces may be level or slanted inward to catch more precipitation and ameliorate the harsh microclimate.

Site preparation can be accomplished on fairly steep ground by use of a small tractor equipped with a reversible double disk plow and hydraulic vertical lift. This machine will make a single furrow about 12 inches deep and 24 inches wide on ground up to about 40 percent slope. The furrow slice is cut by one disk and cast downhill by the second disk. A tree-planting machine can then ride nearly level with one wheel on each side of the furrow.

Mechanical site preparation should be completed in the summer preceding the year of planting. Then, most soil settling and sloughing will have occurred by the time trees are planted and stock is less likely to be buried. Site preparation by tractors is more efficient when the ground is bare of snow, the soil is below field capacity, and weather is conducive to efficient working conditions.

Figure 6.--To prepare a site for natural regeneration, this tractor, equipped with a land-clearing blade, is scarifying along contours in a group selection cutting.

Figure 7.--To prepare sites for planting in central Idaho brushfields, parallel contour strips are made by a tractor with a bulldozer blade. Two rows of trees are planted on each strip.

Artificial Regeneration

Artificial regeneration by seeding or planting has been tried experimentally since the beginning of the 20th century in the regions being discussed here. In the northern Rocky Mountains large-scale planting and seeding projects were started to reforest extensive areas denuded by the destructive fires of 1910. Planting of ponderosa pine was largely successful; artificial seeding was nearly always unsuccessful. Planting became the dependable and established method of starting new forest crops (Wahlenberg 1925). In spite of many failures in these early trials, direct seeding has always appealed to foresters because the procedures appear to be simple and inexpensive, and to provide a method of regenerating large areas in a short period of time. Later, more intensive experiments helped define the conditions under which seeding can succeed (Schopmeyer and Helmers 1947). Seeding has never been used extensively, however, and planting has continued to be the most common method of artificial regeneration.

In the Intermountain area seeding and planting trials were started later than in the northern Rocky Mountains, and the results were different. Both seeding and planting were considered failures in early experiments in central Idaho and Utah, and tests continued into the early 1940's without success. In 1954 a reappraisal of past planting trials led to the establishment of the Town Creek planting study in central Idaho (Curtis and Coonrod 1961). This large-scale test led to the conclusion that thorough and adequate site preparation and careful handling and planting of the nursery stock were essential to high survival of ponderosa pine. Since the Town Creek study, planting has become an established method of regenerating brushfields and timber sale areas on the National Forests of the Intermountain Region. Although some acres are seeded nearly every year, direct seeding has not been used on an operational scale.

Seed Source

Selection of a proper seed source is an important first step in any reforestation project. Ponderosa pine seed source studies have confirmed the long-held belief that the local seed source is best (Weidman 1939, Squillace and Silen 1962). Native trees growing on or near the regeneration site are most likely to be adjusted to the climate, soils, and other environmental factors.

Elevation of the seed source has been shown to be important in site choice within the local area. On sites where planting stock came from seed sources at various elevations, trees from elevations similar to the planting site have proven superior in the long run (Callaham 1960). The superiority of similar-elevation sources shows up in growth rate, form, and adaptation to environmental hazards such as temperature and moisture extreme. Latitudinal distance from the planting site is also important, but limitations have not been determined closely. Very likely, some site characteristics such as aspect are as important as horizontal distances, but their importance has not been proven. If local seed collection zones have not been determined, seeds should be collected from stands in the same habitat type, within 500 feet vertically, and as near as possible to the area to be regenerated. Initial survival is no indication of later thriftiness. Trees and stands from distant seed sources may survive and grow well for a time, only to be killed or severely damaged by an extreme local climatic condition such as cold or heat (Kempff 1928, Squillace and Silen 1962), or to decline in vigor as they grow older.

The characteristics of individual seed trees deserve attention. Parent trees that will produce genetically superior progeny cannot always be selected by visual observation. There are guides, however, which suggest some general things to look for in selecting superior trees (U.S. Forest Service 1948). For reasonable safety, seed should be collected from the better-than-average trees in the stand and from better-than average stands.

To provide a more abundant and regular seed supply from a known source of good genetic quality, seed production areas have been developed. They are selected to provide seed for a particular area or zone, with a special reference to elevation. On each one, the most vigorous and well-formed trees of an existing stand are released to a spacing of about 30 feet and treated to promote seed production. The effects of spacing, irrigation, fertilization, cultivation, and insect control on seed production need to be determined. The most promising measures will be used to promote seed production in these stands.

Eventually, some seed for direct seeding and nurseries will come from seed orchards of selected trees that have demonstrated ability to produce progeny with specific genetic characteristics we value. Desirable characteristics might include resistance to some disease or insect, increased growth rate, improved wood quality, drought resistance, or improved crown quality for esthetic uses such as Christmas trees. The characteristics desired may vary with ownership and locality.

Seed Production and Storage

Ponderosa pine is a variable producer of seed, and heavy cone crops occur infrequently (Curtis and Lynch 1965). In western Montana, only one "good" crop and five "fair" crops were recorded in 23 years of observations (Boe 1954). In central Idaho, three very heavy cone crops were reported from 1935 through 1958 (Curtis and Foiles 1961).

Ponderosa pine trees produce large numbers of cones and seeds in years of heavy crops (fig. 8). For example, cone yields from the very heavy crop of 1936 in central Idaho (table 2) averaged from 222 cones per tree on immature trees to 1,409 cones per tree on mature scattered trees. Seed yields from the same crop averaged from 16,100 seeds per immature tree to 118,300 seeds per mature tree (U.S. Forest Service, Intermountain Forest and Range Exp. Stn. 1937).

The reasons for the variability of seed crops are not fully known, but some observations and measurements have been made. In a northern Idaho study, pollen dispersal was greatly reduced in years when rains fell during the pollination period (Turner 1956). The amount of seed killed by cone and seed insects can be extremely high in some years (Keen 1958). A surprising number of birds and small mammals also consume seed before it falls to the ground (Curtis 1948). Such losses are important in years of light or medium seed production. Squirrels (*Sciurus* spp.), chipmunks (*Eutamias* spp.), and mice (*Peromyscus* spp.) are unquestionably responsible for the greatest losses in seed, both from the tree and after dissemination. In western Montana and in central Idaho, mice, chipmunks, or shrews (*Sorex* spp.) destroyed over 90 percent of fallen ponderosa pine seed (Adams 1950; Foiles and Curtis 1965b; Schmidt and Shearer 1971). In another study in western Montana squirrels not only destroyed close to 85 percent of the cone crop, but by the nature of their clipping, destroyed the current year's seed, the 1-year-old conelets, and the flowering potential of the trees from which cones were clipped (Squillace 1953; Adams 1955; Schmidt and Shearer 1971). It was concluded from these studies that squirrels can harvest most of the seed crop in light and medium seed years, thus minimizing the chances of adequate reproduction establishment. Prevention of cone losses from standing trees by using metal bands to repel squirrels and so protect a supply of genetically desirable seed proved successful in western Montana (Tackle 1959).

Figure 8.--Branch ends of ponderosa pine trees are heavily laden with cones during years of heavy seed crops.

Table 2.--*Mean yields of ponderosa pine cones and seeds from a very heavy crop, 1936, in central Idaho*[1]

Tree	Altitude	Age	Cones per tree	Cones per bushel	Seeds per cone	Seeds per tree	Fanned seed per pound
	Feet	*Years*					
Immature, stand	4,000	46	300	302	64	19,700	8,575
Immature, stand	5,500	38	222	251	77	16,100	8,050
Immature, isolated	4,000	42	586	267	80	43,000	8,200
Immature, isolated	5,500	36	368	281	74	24,500	8,450
Mature, scattered	4,500	150+	1,407	268	71	101,000	8,350
Mature, scattered	5,500	150+	1,409	227	92	118,300	8,875

[1]From Annual Investigative Report 1936-37, U.S. For. Serv., Intermt. For. & Range Exp. Stn.

Figure 9.--Squirrel caches of ponderosa pine cones are convenient sources of seeds, but the parent trees cannot be identified.

Attempts employing repellents to prevent small rodents and birds from consuming freshly fallen seed have been unsuccessful in central Idaho (Foiles and Curtis 1965b). Rodent eradication was successful in Oregon but required three distributions of poisoned bait (Stein 1964). In California, five patch cuttings, ranging in size from 7 to 38 acres, were baited prior to direct seeding in 1964 and 1965 (Hall 1967). In that experiment 175 acres were baited, including buffer zones, to protect 84.5 acres of seeded area. When total costs were applied to the seeded area, labor costs averaged $1.55 per acre and bait $0.67 per acre--a total of $2.22 per acre. Birds, especially grouse, can be a source of disfigurement and mortality to young natural stands and plantations, but such damage is not severe or widespread (Sparhawk 1918; Curtis and Elder 1965). A study in western Montana measured the progress of mortality during the entire cone development period (Shearer and Schmidt 1970). Three-fourths of the potential cones aborted or failed to develop because of some undetermined factors. Squirrels reduced the crop an additional 14 percent, and insects and miscellaneous other factors destroyed another 5 percent. Only 6 percent of the potential cones completed their development and disseminated seeds.

Seed collection.--Picking cones from trees can be a difficult task. Cones are most abundant near the top of the crown and at branch ends, where they are difficult to reach. They can be collected from squirrel caches on the ground, although their genetic quality is then unknown (fig. 9). Sometimes cones can be collected conveniently from felled trees on areas that are being logged. If seed orchards and seed production areas are on nearly level ground, truck-mounted mechanical hoists may be an economical method of reaching cones quickly and safely.

Figure 10.--These typical ponderosa pine seeds are from a very heavy seed crop in central Idaho.

Ripe cones have a specific gravity of 0.80 to 0.86 in central Idaho (Maki 1940). The degree of ripeness can be tested by dropping closed cones into kerosene or a half-and-half mixture of kerosene and raw linseed oil. When most of the cones from a tree float, the seeds from that tree are ripe. The float test should be applied only to freshly picked cones.

Seed storage.--The infrequency and irregularity of ponderosa pine seed crops make seed storage necessary in a program of artificial regeneration. Fortunately, very heavy cone crops generally produce high percentages of good seed (fig. 10), which can be stored for use during intervening years.

Ponderosa pine seeds have been stored successfully for 14 years when dried to less than 10 percent moisture content and placed in sealed containers at a constant temperature near 32° F (Curtis 1955b). Other workers (Allen 1957, Barton 1954, Schubert 1955) have reported successful storage at temperatures from 32° F to 0° F, although temperatures near 32° F were the best.

Direct Seeding

Direct seeding has never been used extensively in the northern Rockies although some areas are seeded nearly every year. Summaries of the results of extensive early tests report many failures and a few successes (Wahlenberg 1925; Maki 1938). Contributing factors in most successes were believed to be thorough elimination of competition and favorable weather patterns (Wahlenberg 1925). Many of the early seedings were attempted on very dry sites where planting had failed previously. The knowledge gained

from summaries of previous tests was used in a series of direct seeding trials in northern Idaho and western Montana during the period 1937 to 1940 (Schopmeyer and Helmers 1947). Results show that with effective protection from animals ponderosa pine can be seed-spotted successfully on favorable sites that have been recently and severely burned (Helmers 1946).

The two major difficulties in direct seeding are animals and the harsh environmental forces (Wagg and Hermann 1962). Hand-sown seed and the seedlings germinating from them suffer from the same agents of first-year mortality as naturally sown seed and seedlings. Planting, on the other hand, partially overcomes these destructive agencies.

Ground preparation.--Any of the methods described in the section on site preparation can successfully reduce competition, but for direct seeding a method that exposes mineral soil should be chosen because pine seeds germinate best in that medium. Cultivating or loosening the soil on the spots before sowing increased germination in one test (Loewenstein and Pitkin 1966) and had no appreciable effect in another test (Schopmeyer and Helmers 1947) in northern Idaho.

Sowing rates.--In early seeding studies the tendency was to sow large numbers of seeds to insure establishing some seedlings. For example, 20 to 25 seeds were sown per spot, and this often resulted in spots with many seedlings in close competition. Some foresters believed the excessive numbers of seedlings necessitated thinning to prevent stagnation, loss of growth, or the development of poorly formed trees (Stein 1957; Wagar and Myers 1958). One northern Idaho study showed that the number of seedlings per spot significantly affected both diameter and height growth of dominant ponderosa pine trees for 17 years after spot seeding (Foiles 1961). Although a satisfactory stand developed without thinning, sparsely stocked plots had a notable growth advantage.

In recent years, a trend toward reduced sowing rates reflects greater experience with direct seeding and a preference for lower initial stocking in reproduction stands. Most management guides now recommend 400 to 500 established seedlings per acre. Sowing rates should be based on the ratio of the number of viable seeds sown to the number of established seedlings at some predetermined age. Unfortunately, the seed-to-seedling ratio is not easy to predict. It varies by sites and is affected by site preparation, seed viability, weather in a particular year, seed protection measures, and other factors. Tests of seeding on different sites are needed to develop seed-to-seedling ratios for sowing guides and to help determine which sites can be seeded economically. Until results are known, the germinative capacity of individual seed lots will help determine sowing rates.

Sowing season.--Fall sowing usually has been more successful than spring sowing (Wahlenberg 1925; Schopmeyer and Helmers 1947). Fall-sown seed is stratified naturally over winter and is ready to germinate early in the spring. Spring sowing is often delayed because the planting sites are inaccessible until mountain roads become passable. If seed can be sown early enough, however, spring sowing does have an advantage over fall sowing; protection from rodents and birds is needed for a much shorter time.

Seed protection.--Various methods of protecting planted seeds from rodents and birds have been tried (Wahlenberg 1925; Schopmeyer and Helmers 1947; Maki[4]). In experimental seedings, losses to rodents have been reduced effectively by placing wire screen cones over seed spots, but the screening method is too expensive for general use.

[4]T. E. Maki. Artificial seeding of tree species in the Intermountain Region. Intermt. For. & Range Exp. Stn., Moscow, Idaho. File rep., 45 p. 1938.

Baiting the area with poison grain and sowing repellent-coated tree seeds have had considerable success. Many poisons and rodenticides have been tested in various parts of the United States with varying effects, but none has worked consistently enough to be universally accepted. In recent years, the most commonly used treatment has been to bait the area with poison grain and then sow seeds coated with a combination of the poison endrin, a fungicide thiram, and a bird repellent aluminum powder in a latex carrier.

When need for rodent control is anticipated, the advice and cooperation of a professional control organization, such as the Predatory Animal and Rodent Control division of the Fish and Wildlife Service, should be sought. Control officers can advise on methods of estimating the kinds and relative numbers of seed-eating mammals on the area to be treated. When the population survey is completed, they can assist foresters to secure recommended baits and poisons, and can supply instructions on treatment and safety precautions for handling and distributing the poisons. The use of many chemicals has been restricted because of danger to other than target animals. Before any chemical is used, assurance should be secured that it is currently registered and approved for the specific purpose anticipated.

Planting

Planting is the most commonly used method of artificial reforestation in both Intermountain and northern Rocky Mountain forests. Nearly 45,000 acres were planted in 1970. Hand planting is the usual method, although machines are used successfully. In recent years an increasing share of the site preparation and planting has been awarded to private contractors who hire the crews and complete the job to written specifications.

Nursery stock production.--The production of healthy stock from nurseries is essential to reforestation by planting. Stock must be in condition to grow when it is outplanted. Causes of past failures include insufficient site preparation and careless handling and planting of stock. At present, nurseries in the Intermountain Station territory are producing suitable and healthy ponderosa pine stock, as confirmed by the high survival rates of recent plantings.

Even though forest nursery tree production techniques are satisfactory, greater efficiency would be achieved through better methods of seed treatment and nursery bed weeding. More precise studies of fertilization and irrigation schedules and seedbed spacing should improve stock production and vigor. In the long run, probably the greatest benefits will come from basic studies of seed and seedling physiology and genetics. Recent studies in California have led to development of methods of determining the root-regenerating potential (RRP) of nursery stock and how it varies with different nurseries and nursery practices (Stone and Schubert 1959a and b; Schubert and Baron 1965; Stone and others 1963).

The main requirement for good ponderosa pine nursery stock is a healthy root system 10 to 12 inches long (Curtis and Coonrod 1961). If such stock is well planted, the roots have a chance to stay ahead of the receding soil moisture level during the dry summer months. The roots should be in balance with a healthy top; a root-top ratio of 1.5:1 or 2:1 is desirable.

The most common age of planting stock used in these regions in recent years has been 2+0 seedling stock. Most of the earlier plantings used some form of transplant stock ranging from 1+1 to 2+2, but a 1954-58 study showed that 2+0 plants survived nearly as well as 2+1 stock on well-prepared sites (Curtis and Coonrod 1961). Fifth--year survival of 5 successive years of planting averaged 82 percent with 2+0 stock and 94 percent with 2+1 stock on stripped and trenched sites. The lower survival rate of 2+0 stock is compensated for by the lower cost of producing and planting seedlings as

compared to transplant stock. Recently, tests of planting 1+0 seedlings have begun. Nurserymen believe they can grow 1+0 ponderosa pine stock suitable for planting, especially on well-prepared sites.

Raising seedlings in inexpensive containers and then outplanting both the seedling and container is a method being either tested or used successfully in several forested regions (Jones 1967; Kudrjavcev 1965; Williamson 1964). Planting containers or tubes of various materials, sizes, and shapes are being tested. Advantages claimed for this system include minimizing production time, cost, and initial planting shock; prolonging the planting season; and increasing survival on certain sites. Commonly the tubelings are planted in the field 6 to 8 weeks after seed germination. At that stage of growth, the roots have not reached the bottom of the container, so root growth is not interrupted during outplanting.

Container planting was tested in central Idaho as a means of increasing survival on dry sites (Curtis and Foiles 1964). Sixteen kinds of containers, 10 to 18 inches long and made of several different materials, were planted on various sites and in two seasons, spring and fall. Seedlings were grown in the tubes for 1 and 2 years before outplanting, rather than for 6 to 8 weeks. Relatively long containers were used to minimize root competition and to provide the taproot with a better chance of remaining in moist soil. Container planting did not improve survival under the conditions tested in central Idaho. Possibly some other form of container planting will prove advantageous in the future, but for the present, survival of bare-rooted stock is satisfactory.

Stock lifting and storage.--In California, date of lifting and length of time in storage strongly affect the root-regenerating potential of outplanted stock (Stone and Schubert 1959b). The optimum time for lifting and storing stock needs to be determined for each forest nursery in the Intermountain Station territory. Usually, ponderosa pine stock is lifted in early spring and stored at near-freezing temperatures for periods of a few days to 8 or 10 weeks with carefully controlled humidity. This schedule agrees with Stone and Schubert's recommendations from California for timing the lifting and planting operations to take advantage of the period of peak root growth in the spring.

Stock shipment and field storage.--The best method of packing and shipping nursery stock depends on weather conditions, distance, and time in transit. The stock must be protected from heating within bundles and from excessive drying by sun and wind. Roots will die after a few minutes of exposure to dry air. Furthermore, the right combination of heat and moisture in bundles can prompt the breaking of dormancy, which can be as fatal to seedlings as excessive heat.

It is seldom possible to plant trees the same day they are delivered from the nursery; therefore, some kind of field storage is necessary. In the past, most stock was heeled-in on the planting site and taken out as needed for immediate planting. In recent years, however, that method has been largely replaced by cold storage accessible to the planting site.

Heeling-in consists of storing the stock in trenches with the tops exposed and the roots covered with tightly packed damp soil. If this method must be used, as in remote planting sites, storage should be for as brief a time as possible, in damp, shaded soil. After more than a few days, warm weather is liable to cause the plants to break dormancy and start growth; then disturbance is a greater shock than the original lifting and storage. Lifting trees after growth has started may interrupt root growth and delay root initiation after outplanting.

Bundles of trees can be stored in cold storage plants if these are available near the planting site. Temperature of 33° to 40° F and humidity of 90 to 99 percent is desirable, with free air circulation through the room.

Storage in snow has proven successful and convenient for most planting projects in the Intermountain Region (Curtis and Coonrod 1961). The trees, still packed in nursery bundles, are buried in snow; sometimes snow is collected and placed in small sheds constructed for tree storage at a central location such as a Ranger station, but more often snowbanks along roads at higher elevations than the planting site are used. Each day enough trees for the day's planting are transported to the planting site and kept in snow inside a tent. The trees are sorted, graded, and placed in planting bags inside a tent. This procedure minimizes the exposure of planting stock to drying from heat and wind before it is planted.

Field planting.--Shallow soils make planting difficult because some soil must be removed in preparing the site, and too little may remain. If the site is prepared by stripping, plowing, or furrowing with tractors, 18 inches or more of soil may be displaced. On steep slopes where manual labor replaces machines in the site preparation and planting process, the 8- to 12-inch roots of the planting stock require at least 18 inches of soil to survive and grow. Therefore, it is inadvisable to plant sites having less than 24 inches of soil.

Ponderosa pine plantings have been attempted in both spring and fall. Earlier research suggested that early spring was generally the best season for planting in this region (Schopmeyer 1940). In recent years, however, both fall and spring plantings have been successful under certain circumstances. Fall planting has been recommended for high elevation sites where the trees are protected by an early snow cover. Deep snow also makes these sites inaccessible during the early spring planting season. Ponderosa pine is most often planted on low elevation sites, however. These are accessible in early spring and do not receive a protective snow cover until late in the fall. Therefore, ponderosa pine is usually planted as early as possible in the spring.

Several different hand planting tools have been used, including shovels, mattocks, planting bars, modified one-hand mattocks, and backpack power-driven augers. These tools have given satisfactory survival when good stock was planted on well-prepared sites and the recommended planting technique was carefully followed. The kind of soil and its stoniness, steepness of slope, kind and amount of site preparation required, and custom all influence choice of planting tool. Detailed descriptions of the precise technique for each tool are available in textbooks and manuals (Toumey and Korstian 1942; Lynch 1952; Corson and Fowells 1952). With any method, a little extra care in planting can easily increase survival 10 to 20 percent (Cushman and Weidman 1937).

In Intermountain forests, planting on contour strips is common. In this method, an influential factor is the spacing pattern of trees on the strips, which may be 30 feet or more apart on slopes up to 60 percent. The usual practice is to plant two rows of trees about 3 feet apart on the strip, with 8-foot spacing of trees in staggered rows. There is danger that trees in this spacing pattern may grow much like open-grown trees, at least on one side, thus reducing wood quality. Group plantings on the strips can possibly improve the quality of at least some trees, which could be favored as crop trees. The effects of different spacing patterns on growth and yield and quality of trees planted on bulldozed contour strips need further study.

Where the ground is prepared by terracing, some soil is displaced from the inside of the terrace to the outside, thus creating a range of soil conditions across the terrace. Trees can be planted on the inside of the terrace near the cutbank, in the middle of the prepared surface, or on the outside in the fill soils. Nursery stock and potted seedlings were planted in three rows on the inside, middle, and outside of terraces in central Idaho to determine the most favorable position (Curtis and Foiles 1964). Survival of trees was significantly highest on the inside of the terrace, intermediate on the middle, and lowest on the outside of the terrace where the loose fill soil dried rapidly.

Figure 11. This ponderosa pine plantation was planted by machine in previously prepared furrows.

The range of soil conditions across a terrace affects height growth as well as survival of planted trees. Analyses of planting tests conducted over 5 years showed that trees planted near the cutbank were significantly taller than trees near the outside of the terrace 10 years after planting (Hall and Curtis 1970).

Towed planting machines have been used in Intermountain forests with good results on prepared ground and on moderate slopes (fig. 11). A crew consists of three men: the tractor operator, a planter on the machine, and a followup man who walks behind the machine to inspect the planted trees and correct any faulty planting, especially incomplete tamping. The planter and the followup man alternate jobs.

Survival of machine-planted ponderosa pine has been high for the few years that this method has been used. It was compared with hand planting in one test in central Idaho in 1960. Four 10-acre plots had been aerially sprayed with herbicides to eliminate the brush competition. Half of each plot was hand planted without further site preparation and half was furrowed and machine planted. Two-year survival on the machine-planted plots averaged 77 percent on east aspects and 71 percent on west aspects. Survival on hand-planted plots averaged 17 percent on east aspects and 6 percent on west aspects. The poor survival on the hand-planted plots was attributed to a rapid invasion of cheatgrass (*Bromus tectorum*) after the brush was killed. Furrowing removed the cheatgrass seeds from the machine-planted trees. Although the comparison was not conclusive because of poor survival on the hand-planted plots, machine planting was successful, and many acres elsewhere planted by machines have shown survival as good or better than in this test. Since 1962, private planting contractors have relied on hand planting because it requires no investment for equipment and because machines are restricted to gentler slopes.

Machine planting has several advantages over hand planting:

1. More consistent quality of planting. Every tree is planted in the same way.

2. High rate of production. The machines used in the Intermountain Region planted 4,000 to 8,000 trees per 8-hour shift and the machines could be run for two shifts a day, especially important when the planting season is short.

3. Lower overhead costs.

Some disadvantages of machines include:

1. Limitations of slope. They cannot work ground steeper than about 40 percent.

2. Dependence on machines. If the tractor or planting machine breaks down mechanically, the whole crew loses time.

3. The high cost of purchasing specialized machinery that is used only a few weeks each year.

Planting machines will be more useful in mountain country when a machine is developed that can work on contours on slopes steeper than 40 percent. Also, machines need to be better adapted for work in rocky and log-strewn areas.

Natural Regeneration

Characteristic of ponderosa pine forests is the obvious presence of advance reproduction. Seedlings may occur singly or in small or large groups, depending on conditions at the time of their establishment. Advance reproduction is mentioned in ponderosa pine literature as occurring in "waves," interpreted to mean that although small numbers of seedlings may occur from year to year, they are established at irregular and unpredictable intervals in considerable abundance and over areas of several hundred thousand acres or more. This phenomenon of a wave of natural seedling establishment, aided by higher than usual moisture and cool temperatures, occurred in central Idaho in 1963 (Foiles and Curtis 1965a), the first instance since 1941. The classic example, in Arizona in 1919, was the only one during a 38-year period between 1908 and 1945 (Pearson 1950).

The presence of some established advance reproduction may give the impression that considerable numbers of seedlings are established almost annually. Unfortunately, successful coincidences of ample germinable seed and favorable growing conditions cannot be relied on because they cannot be effectively predicted. If, however, a heavy seed crop is in evidence, the forester may consider several logging methods that provide for natural regeneration in different ways. When advance reproduction is present, carefully planned harvest cutting is needed to protect the young stand from excessive logging damage.

Seed Dissemination

Whatever the reproduction cutting method, seed must be disseminated from trees on or near the area to be regenerated. The precise time that seed will be disseminated and the distance that it will travel from seed trees vary widely. Weather at the time of seed maturation and dissemination, heights and positions of seed trees, topography and altitude of the location, nature and duration of the air turbulence during dissemination, and degree of cone persistence all affect the time, place, and quantity of seed fall. In a central Idaho bumper crop, 254,000 seed per acre fell in virgin forest, 203,000 per acre in a selectively cut stand (with residual volume of 4,047 board feet per acre), and 243,000 per acre in a 70-year-old second-growth stand (U.S. Forest Service, Intermountain Forest and Range Exp. Stn. 1937). In western Montana, ponderosa pine seed reached the ground at the rate of 104,000 per acre in a selectively cut stand with residual pine volume of 4,760 board feet per acre (Squillace and Adams 1950).

Figure 12.--A seed tree cutting in a western Montana ponderosa pine stand.

Figure 13.--A shelterwood cutting followed by ground scarification resulted in adequate ponderosa pine regeneration.

Reproduction Cutting Methods

Clearcutting.--Seed production and seedling survival records enable the forester to estimate the size of cone crop needed to attain a reasonable goal of 1,000 seedlings per acre. A test in small clearcuts in central Idaho determined the ratio of seeds to established seedlings to be 55:1 on scarified soil in weather somewhat warmer and drier than normal (Foiles and Curtis 1965b). Under these conditions an adequate seedfall would be 55,000 seeds per acre in the center of the clearcut openings. In Oregon, a study of seed dissemination into a clearcut from the edge of an uncut stand showed that seedfall 2 chains from the timber edge was only about one-fourth as much as seedfall under the timber (Barrett 1966). Therefore, the margin of a timber stand must produce at least 250,000 seeds per acre to result in the required 55,000 seeds 2 chains from the timber. Only a very heavy cone crop produces this seedfall (Foiles and Curtis 1965a, Barrett 1966); only such a crop, therefore, can be considered adequate to regenerate small clearcut openings in one year. In bumper crop years, dominant trees 40 years old and older are heavily laden with cones, obvious even to the casual observer. Not all sites are regenerated in one year, however. In areas with favorable climatic conditions, several medium cone crops over a period of 3 to 6 years might be as good as one bumper crop.

On clearcuts, then, the longer dimension should be at right angles to the prevailing wind and the shorter dimension should not be more than 260 feet as a maximum width; 200-foot widths would be preferable for better assurance of adequate seed distribution.

Of course, clearcuts can be larger if a combination of natural and artificial regeneration methods is used. Natural regeneration may be planned for a distance of about 130 feet from the timbered edges; the remaining interior of the tract can be planted or seeded artificially.

Seed-tree and shelterwood.--Both seed-tree and shelterwood cuttings remove only a part of the stand; the remaining trees are cut after the reproduction is established. Though insuring a supply of seed, the two cutting methods have the disadvantage of subsequent reproduction losses from logging the residual stand. Dominant, vigorous seed trees should be selected for either the seed-tree or shelterwood system. Such trees, if they are free of disease, are likely to be good seed producers and resistant to wind and other damaging agents.

Seed-tree and shelterwood cuttings have been used successfully by private industry and on the National Forests in western Montana and northern Idaho (figs. 12, 13). Seedfall and reproduction resulting from one trial of these methods were measured in southern Idaho. Two L-shaped areas on the Boise Basin Experimental Forest at Idaho City, totaling about 10 acres, were chosen prior to the very heavy seed crop of 1958. Each area contained an east and a south aspect. One area was scarified by a land-clearing blade, the other by 12 disks, 36 inches in diameter; both devices were front-mounted on a D-7 tractor. Both areas supported deep and shallow soils and 90-year-old ponderosa pine singly and in groups. These areas resembled seed-tree and shelterwood cuttings only on a limited scale, but nevertheless provided interesting comparisons of first-year seedfall, seedling numbers, and stocking 3 years after dissemination (table 3).

For natural regeneration on cutting areas wider than 260 feet, with reproduction density that will provide adequate stocking after 3 years, the seed-tree method rather than clearcutting should be used. Assuming the seed trees are mature (over 150 years old), the number needed will depend on the seed yield. At the 55:1 ratio of seeds to established seedlings, two or three spaced trees per acre are required for full coverage of the area if a heavy crop of seed (100,000 per tree) can be predicted. We estimate

Table 3.--*Density of seed dissemination, established seedlings, and stocking per acre 3 years after dissemination for seed-tree and shelterwood plots on the Boise Basin Experimental Forest, 1958*

Scarifying tool	Seed-tree plot				Shelterwood plot			
	Seed per acre	Seedlings per acre	Stocking percent[1]	Seeds per seedling	Seed per acre	Seedlings per acre	Stocking percent	Seeds per seedling
Land-clearing blade	202,000	3,476	87	58	255,000	4,690	90	54
Disks	33,120	304	42	109	172,560	1,360	72	127

[1]Stocking percent = percent of 4-milacre quadrats containing at least one seedling.

that 8 to 12 dominant trees 16 to 24 inches dbh will provide enough seed for regeneration in an average seed year. Reserving this larger number of trees also makes subsequent logging of the seed trees more economical.

Single-tree and group selection.--The selection method (otherwise called selective cuttings, or selection logging, partial cutting) has been employed in the West and in the Intermountain Station territory more commonly to cut ponderosa pine than any other method. Unfortunately, the selection method is subject to a wide variety of interpretations. Textbooks describe the selection method as harvesting the oldest or largest trees in a stand at repeated intervals throughout the rotation (Hawley and Smith 1954). The objectives of the cuttings are to create uneven-aged stands and to regenerate such stands. Most selective cuttings in ponderosa pine forests were not designed to meet fully the objectives of the selection method; rather, they were planned to remove individual trees or small groups selected on the basis of one of several criteria including tree vigor, susceptibility to insect attack, and economic value. Although application of selection cutting has varied, the values of the method have been seen as twofold. First, it was a compromise between clearcutting and leaving the stand untouched, maintaining reserve volume as growing stock that would provide high net increment per acre in the residual stand. Second, the reserve trees would provide a seed source, a reservoir for the future. As an added advantage, the method demonstrates to the public that foresters are not stripping cover from watersheds and ruining the beauty of the countryside. A real disadvantage is, however, that unless the cutting is designed with skill and understanding, the result can be the high-grading of a stand, so that it consists of low-quality trees after cutting.

Some ponderosa pine stands appear to be all aged. Usually these consist of two or three separate age classes, but include all crown classes because trees have developed unevenly over a long period of time. Selection management with a long rotation is possible in these stands if the early cuttings are made carefully to develop the size classes needed for future cutting cycles. A rotation of 160 to 200 years is necessary because both tree growth and regeneration are slower under these conditions. Natural reproduction is established only by an infrequent good seed crop followed by a growing season with favorable weather. The selection system has the advantage of maintaining a continuous stand of timber that is esthetically pleasing and protects the sites.

Because early single-tree selection cuttings varied in purpose and execution, they are difficult to evaluate. Reproduction establishment was greater after cutting than before in one of these early cuttings in western Montana (Boe 1948); volume of the

Figure 14.--In an opening resulting from a group selection cutting in central Idaho, ground was scarified just before seedfall from a heavy cone crop.

reserve stands did not greatly influence levels of reproduction or stocking 35 years after cutting. In contrast, later cuttings in central Idaho showed a decrease in density of reproduction over a 15-year period following cutting, although stocking remained dense (Wilson 1951). A 1932 study of cuttings made between 1906 and 1924 on the Boise National Forest showed a striking deficiency in establishment of postlogging reproduction except where 26 years had elapsed since cutting (Curtis 1950).

As more information became available from research, the kinds or types of trees removed in these stemwise selection cuttings changed (Keen 1943). The *Dendroctonus* bark beetles were found over great areas of the West to be the most important cause of mortality in mature and overmature stands, and marking systems were devised so that those stems considered to be the highest risk were removed in the first cutting (Keen 1943; Salman and Bongberg 1942). Silviculturally speaking these were actually sanitation cuttings, but the effect of their removal was similar to that of single-tree selection cuttings.

The group-selection method is adaptable to a wide variety of ponderosa pine stand conditions. Mature trees are removed in groups or patches instead of singly, and the openings thus created provide conditions satisfactory for regeneration in an even-aged structure. In addition to being satisfactory for timber growth, group selection may improve other forest values such as wildlife habitat, water production, and esthetic quality. The openings vary in size but are usually small enough to become stocked naturally.

In central Idaho the rate and amount of reproduction was studied on scarified areas within openings created by group-selection cutting (Foiles and Curtis 1965b) (fig. 14). Seedfall from a heavy cone crop averaged 245,240 ponderosa pine seeds per acre and ranged from 123,320 to 345,080 per acre. In addition to the pine, an average

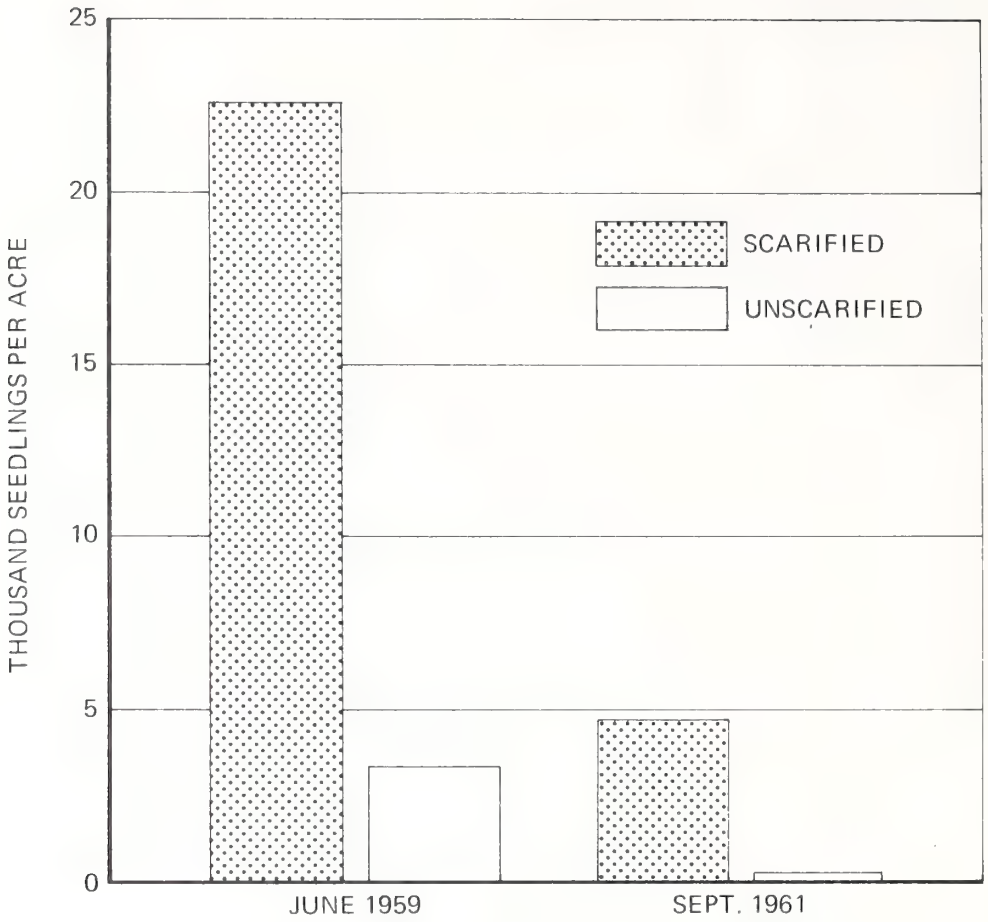

Figure 15.--Many more seedlings per acre were produced on scarified than on unscarified sites following a very heavy seed crop.

of 49,720 Douglas-fir seeds per acre fell in the openings. Even with this amount of seed per acre and near-average growing season weather, some areas were below acceptable stocking (40 percent of milacres stocked) 3 years later. The number of seedlings that germinated was significantly different on scarified and unscarified ground (fig. 15). Germination was poor on unscarified sites, even though large amounts of seed were present; the scarified areas averaged more than 22,000 germinates per acre (fig. 16). During the ensuing 3 years, however, mortality reduced the average number of seedlings on scarified sites to about 4,700 per acre in the fall of 1961.

On scarified ground, the degree of stocking after 3 years varied by aspect. The stocking on ridges and on southwest slopes (from S. 45° E. to N. 45° W.) was lower than on northeast slopes (from N. 45° W. to S. 45° E.) (fig. 17). Mortality reduced the stocking on all three of these sites between June 1959 and September 1961. On ridges and on southwest slopes, stocking was irregular and unreliable as compared to northeast slopes, where all adequately scarified sites were acceptably stocked (40 percent of milacres). These data illustrate that for prompt establishment of ponderosa pine reproduction there must be site preparation as well as an adequate source of seed. Results also suggest that some method of regeneration other than clearcutting may be preferable on sites with southern or western exposure and shallow soils.

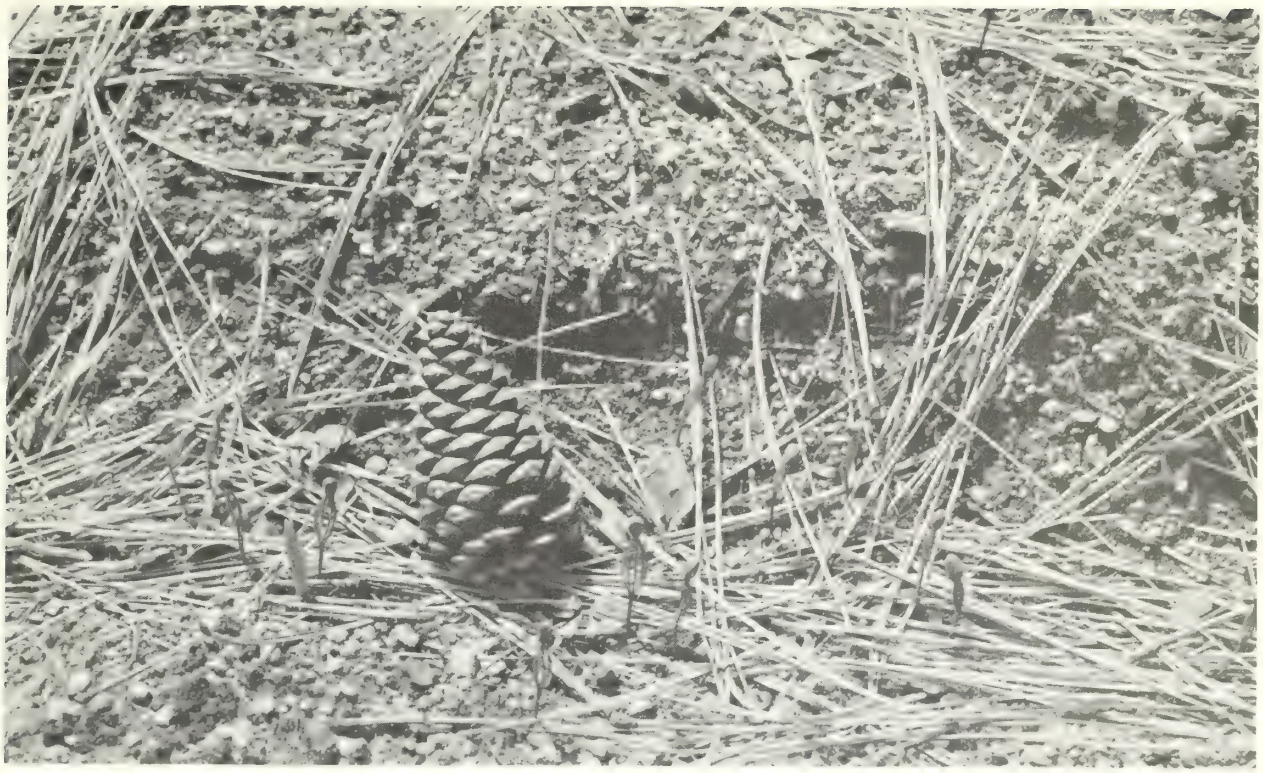

Figure 16.--These newly emerged seedlings are abundant on sites scarified just before a very heavy seed crop.

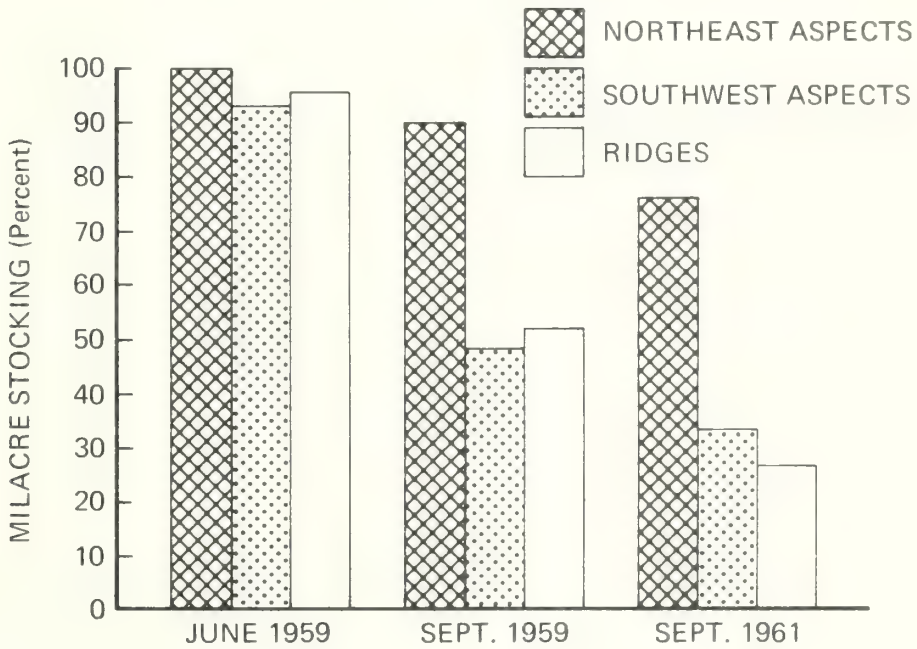

Figure 17.--Aspect affected milacre quadrat stocking on scarified sites following a very heavy seed crop.

Application of Cutting Methods to Habitat Types

The 11 habitat types in which ponderosa pine occurs differ in the relative severity of the regeneration problem under each of the reproduction cutting methods. Which method to prescribe for a particular habitat must be decided by considering the economic consequences in relation to the silvicultural results. The following discussion is limited to an evaluation of the silvicultural aspects of regenerating forest stands in the various habitats.

Climax Position

The four habitat types in which ponderosa pine is associated with *Festuca*, *Agropyron*, or *Stipa* grasses, or a combination of *Purshia* shrubs and these grasses, have similar characteristics and present similar problems of timber management. They are on the dry and warm end of the moisture-temperature gradient for tree growth, ponderosa pine is the climax tree vegetation, and pine stands are often infected with dwarfmistletoe. In these stands dwarfmistletoe is a prime consideration. The only known practical way to prevent infection in the new stand is to eliminate the source--the infected trees--and clearcutting, with seeding or planting, is the most practical method of doing it. Other cutting methods could eliminate the sources of infection if it was not heavy.

If dwarfmistletoe is absent a wider selection of cutting methods is available. All of the high-forest methods of reproduction have been used in these stands with some success. Ponderosa pine is the only tree species present; so competition with other species is not a consideration. Natural regeneration is often sporadic and difficult to obtain, however, because of the hot, dry site, competition from grasses for what soil moisture is available, and the infrequency of good seed crops. Clearcutting and planting produce the quickest and fastest timber growth if they are compatible with the overall management objectives of the area. The site is thoroughly prepared for planting to reduce competition from grasses sufficiently to insure adequate survival of the planted trees.

Group selection, seed-tree, or shelterwood methods, if properly executed, can be applied to stands on these habitat types. Care must be taken to develop the desired age classes. Such cuttings produce enough seed for regeneration, but the competitive grass cover may increase following cutting. Therefore, the site must be prepared shortly before a good seed crop occurs. Then the new crop should be released in a few years by removal or reduction of the seed-tree or shelterwood overstory. Careful logging is required to avoid excessive damage to the reproduction stand.

The *Pinus-Symphoricarpos* and *Pinus-Physocarpus* habitat types are the most productive of the six types in which ponderosa pine is the climax tree. Dwarfmistletoe, a threat in the drier types, is absent in these two. Inconsistency of seed production and droughty summers are difficulties shared with the pine-grass habitat types. Undergrowth dominated by brush species is a problem not encountered in the grass-dominated associations. The brush cover discourages regeneration in two ways. It is a physical deterrent during planting and competes with young seedlings for water and nutrients. Burning removes the physical obstacle temporarily, but these species regenerate promptly from subterranean organs and dormant seeds in the soil surface. Therefore, mechanical site preparation that removes the brush and exposes mineral soil for a longer time is necessary for planting or prompt natural regeneration.

Clearcutting is the most appropriate reproduction cutting method if timber production is the primary goal. It alleviates the problem of undergrowth of brush, the primary difficulty in reproducing pine in these types. On a clearcut, mechanical site preparation is easier, either by itself or used with fire or chemicals, and thorough site preparation is essential to prompt regeneration. In addition, clearcutting allows trees in the new stand to grow where they grow best--in the open.

Seed-tree and shelterwood systems are successful if properly applied. The ground should be prepared, exposing mineral soil, shortly before seedfall from a good cone crop. Once established, trees in the young stand will survive and grow satisfactorily for at least 20 to 30 years, so immediate removal of the overstory is not necessary. Growth of the young trees will be faster, however, if the overhead shade is removed.

Selection management with a long rotation is possible under the conditions recommended for the ponderosa pine-grass habitat types. That is, cuttings should be carefully designed to develop age classes needed for the future. Selection management should be used only when the primary objective is to maintain a continuous stand of timber for an esthetic environment or for site protection, and timber production is only a secondary objective.

Seral Position

Ponderosa pine loses its position as a climax species when moisture becomes adequate for Douglas-fir to reproduce successfully. Then ponderosa pine becomes a seral tree in a series of habitat types in which Douglas-fir is the climax species. The *Pseudotsuga-Symphoricarpos* and *Pseudotsuga-Physocarpus* types have characteristics similar to the associations of ponderosa pine with the same shrub unions. The choice of cutting methods for ponderosa pine in these stands is complicated somewhat by the presence of other tree species with different silvical requirements and disease and insect problems.

Douglas-fir, western larch, and lodgepole pine are common associates of ponderosa pine in Douglas-fir habitat types. Douglas-fir is the most shade-tolerant species in this group, western larch and lodgepole pine are intolerant species, and ponderosa pine is intermediate in tolerance. Therefore, silvically, each species is favored by different methods of cutting.

The choice of method depends largely on the species to be featured in management of the stand. In turn, the choice of species is strongly influenced by disease and insect problems that commonly arise in these habitat types. Dwarfmistletoe infections are severe and frequent in Douglas-fir, western larch, and lodgepole pine, but they do not attack ponderosa pine on these habitats. Spruce budworm (*Choristoneura fumiferana*) commonly attacks Douglas-fir and occasionally western larch. Larch casebearer (*Coleophora laricella*) severely defoliates western larch throughout the region. In addition, bark beetles sometimes cause extensive mortality in Douglas-fir, ponderosa

pine, and lodgepole pine. A particular disease or insect may dictate the choice of cutting methods. Generally, managers try to maintain a mixture of tree species so that no one pest will destroy the entire stand.

Clearcutting followed by planting insures a mixture of species in the stand; it both protects the stand from disease and promotes growth. Where disease and insects are not major problems, any of the high-forest cutting methods are possible, depending on the management objectives. Single-tree selection cuttings promote the natural succession toward pure Douglas-fir, the most shade-tolerant species. Ponderosa pine germinates and survives for 30 to 40 years in the shade, but eventually it ceases to reproduce and is eliminated from the stand. Therefore, the manager should not use single-tree selection cutting if he intends to keep ponderosa pine in the stand.

Group selection, seed-tree, or shelterwood cuttings can provide for stands of mixed species composition. Group selection cutting creates small openings of 0.25 to 2 acres in which all four species will regenerate and grow well following adequate site preparation. Seed-tree and shelterwood cuttings require additional treatments to encourage seed germination. Then the seed trees should be removed shortly after the reproduction stand becomes established to promote growth of pine and larch seedlings.

Ponderosa pine grows best on sites of the *Abies grandis-Pachistima myrsinites* habitat type. Natural reproduction is less sporadic and more dependable than in the drier pine habitats. It will not persist, however, unless satisfactory conditions are present, particularly freedom from overhead shade. Grand fir and Douglas-fir are more competitive than ponderosa pine on these moist sites, and in dense stands they eventually overtop and eliminate pine from the stand. Therefore, cutting methods must provide sufficient light for ponderosa pine. In addition, stands of this type are often subject to serious damage from insects and diseases. Both grand fir and Douglas-fir are attacked by spruce budworm, for example. Grand fir is very susceptible to heart-rot fungi that weaken the trees in addition to destroying much of the wood. The impact of these diseases and insects becomes greater with advancing age of the stand. Under these circumstances, management systems, such as single-tree selection, which lengthen the rotation and increase the proportion of shade-tolerant species, may encourage insects and diseases. Even-aged management of these stands through shorter rotations leads to healthier and more productive forests, with conditions that allow ponderosa pine to form a valuable component of the stand.

As in other habitats, clearcutting and planting create the desired conditions for ponderosa pine most simply. It is important that the planted trees be from a seed source within this habitat type. Again, group selection and seed-tree methods can be successful if they are properly executed.

This evaluation of reproduction cutting methods in various habitat types is based partly on observation of actual practice but largely on the silvical requirements of ponderosa pine. All the cutting methods have been tested in the territory discussed here, though not under all conditions. There is still a need to explore the effects of the various methods in terms of values other than production of timber.

Regeneration Development and Protection

When is a seedling established? This question is difficult to answer. From the time forest tree seed reaches the ground, either in the nursery or in the forest, until the tree is harvested, natural forces work against its survival. Disease, insects, birds, mammals, cold, heat, snow, hail, shade, too much water, too little water, wind, and fire, directly or indirectly, can kill trees of different ages. The first few years of a tree's life are probably the most critical. Until the young tree has had several years to develop its crown and root system, its chance for survival is precarious. A seedling is never established in the strict sense of the word, but we can decide on a time when, for practical purposes, a seedling can be considered so.

The loss of seedlings in the first 3 years after germination or after planting probably represents a greater rate of loss in stems per acre than at any time in the life of a ponderosa pine stand, except for episodes of fire and epidemics (Meyer 1961; Korstian and Baker 1925; Pearson 1950; Tackle and Roy 1953; Foiles and Curtis 1965a). The most important causes of mortality in these first 3 years are drought, insolation, animals, and damping-off and other fungal diseases (Curtis and Coonrod 1961; Foiles and Curtis 1965a). After 3 years the seedlings are stronger and less susceptible to some of these agents. Then others such as higher mammals, insects, diseases of roots and foliage, competing plants, and weather become more prominent (Meyer 1961; Wilson 1952; Adams 1951a,b; Dingle 1956). Because of the rather abrupt change in mortality rate at this time, we may consider a tree seedling established 3 years after the seed has germinated or the seedling or transplant has been outplanted on the forest site.

Losses During Establishment

Drought is the chief cause of seedling loss during the period of establishment. In a large-scale study where 90 acres were planted each year for 5 years and where three classes of stock were planted on three differently prepared sites, drought was believed the principal cause of mortality each year (Curtis and Coonrod 1961). In a 3-year study of natural reproduction establishment, drought and insolation together accounted for 64 percent of total mortality of 1-year seedlings (Foiles and Curtis

1965b). Many times during late June, July, and August, on south and west aspects, mineral soil surface temperatures exceed 152° F, considered potentially lethal to very young seedlings (Baker 1929). Soil moisture measured at 6-, 12-, and 18-inch depths in a mulching study showed that beneath weed-free surfaces on south- and west-facing slopes the wilting point was commonly exceeded at depths to which tree seedling roots penetrated. The moisture deficiency accounted for mortality of some outplanted stock (Hall 1971).

Additional causes of mortality of natural seedlings less than 3 years old are fungi, cutworms, birds, rodents, deer, hail, washing, and burying by eroding soil. Damping-off is frequently responsible for extensive mortality in newly emerged seedlings (Foiles and Curtis 1965b), but is virtually impossible to control under forest conditions. In plantations, apart from drought, animals--hares, gophers, and porcupines--probably account for most losses during the first 3 years, but are commonly sporadic in their attacks.

Losses After Establishment

Logging.--Ponderosa pine advance growth occurs to some extent in nearly all stands of the species. Because reproduction is so difficult to establish, damage to it must be avoided. Some stand damage from logging is inescapable, but planning can lessen the degree of understocking caused by it (Mowat 1940; Curtis 1955a; Barrett 1960). High intensity of cut can result in significantly lower stocking of advance reproduction after logging. On an 838-acre experimental cutting in central Idaho, tractor size, cutting method, and initial volumes varying from 10,000 to 20,000 board feet per acre produced no differences in initial and postlogging stocking, but heavy cutting caused significantly greater damage to the understory than light cutting (Foiles 1962).

Damage to young stands by logging can be reduced by (1) felling trees up or down slopes on areas to be logged by jammer and angled to skid trails in areas to be cat skidded; (2) felling a group of trees in one direction and, if possible, in one place; (3) skidding logs by tractors at right angles to contours and down ridges wherever feasible; and (4) removing all limbs on large trees before skidding to avoid raking, bending, and breaking of seedlings and saplings. The number of chokers should be limited to from three to five, depending on the size of the logs, to prevent the load from fanning, making an unnecessarily wide skid trail, and skinning tree bases. To see that these practices are observed, enlisting the interest of the woods boss and crews in management objectives is far superior to relying on supervision. This approach is more educational and enduring in its effects.

Fire.--Fires are a constant threat to any forest stand. Even fast-moving surface fires can wipe out the youngest age classes completely (Connaughton 1936). They occur frequently and are difficult to control in the ponderosa pine type. Fortunately, State, federal, and private fire control organizations are prepared for these annual emergencies with revised fire plans and the latest equipment. Management plans for reproduction stands should include fire protection.

Disease.--Diseases are potential agents of severe damage to young trees and stands. Diseases that cause only occasional damage under ordinary circumstances may cause widespread destruction under certain favorable conditions. Dwarfmistletoe is often prevalent on certain habitat types, but it can be controlled silviculturally with available guidelines (Boyce 1961; Childs 1963; Leaphart 1963). Root-infecting fungi such as *Fomes annosus* and *Armillaria mellea* cause both mortality and growth loss in young pines. Most root diseases spread from the stumps of cut trees into adjacent stands; therefore, these diseases may become more widespread with increasing application of thinnings. *Elytroderma* needle cast causes considerable damage locally, and is occasionally widespread on ponderosa pine. Unknown pathogens have been suspected of causing mortality

in some plantations (Curtis and Foiles 1962). Because of the virulence of some diseases, the speed with which they act, and the investment made in establishment of regeneration, it is important to maintain efficient forest disease surveys.

Insects.--Young seedlings may be attacked aboveground by grasshoppers, cutworms, aphids, and bark-chewing beetles. One instance of heavy feeding by tussock moth in a ponderosa pine plantation has been recorded (Curtis and Foiles 1962). Root-feeding insects, such as grubs, weevils, wireworms, cutworms, root aphids, and root bark beetles, do their greatest damage to tree seedlings. Ponderosa pine seedlings are attacked by insects that reduce growth, deform, and occasionally kill trees. Insects causing this kind of damage include tip moths or twig moths, weevils, and midges and other gall-forming insects. Bark beetles, especially those of the genus *Ips*, can be very destructive to small, thin-barked pines. Insect populations and the damage caused by them vary greatly by years and locations. Efficient insect surveys will help to indicate potentially hazardous insect populations so they can be avoided or controlled if possible.

Climate.--Injury and mortality from climatic elements account for only a small percent of losses in established ponderosa pine regeneration. Extremes of climate or weather can be very destructive, however, especially in plantations grown from the wrong seed source. Snow and wind are also capable of causing understocking in sapling stands.

Mammals.--Mammals such as ground squirrels, pocket gophers, rabbits, hares, porcupines, and deer can cause malformation or mortality of stems of apparently established seedlings by their feeding. Defects often develop in the trees if they survive the attacks. The feeding of these animals is usually confined to small areas, and reflects either habitat conditions or sudden population increases. Nevertheless, understocking to a greater or less extent can result. Hares (Hall 1971), porcupines (Baker and others 1921; Wilson 1952), pocket gophers (Dingle 1956), and deer (Adams 1951a,b) are probably the most common and the most destructive.

The most common injury to established regeneration is from rodents. For control, the particular mammals causing damage must be identified. Keys are helpful in distinguishing these animals and the damage they inflict on the tree (Pearce 1938, 1947; Lawrence and others 1961).

Rabbits and hares are perhaps the easiest to control by the distribution of poisoned grain or alfalfa in suitable places, although the proper timing may not be evident until some feeding activity has been observed. Professional wildlife personnel can be helpful as advisors.

Various methods have been employed to reduce porcupine populations, but baiting with wooden blocks containing strychnine is the simplest and most effective (Hooven 1971). Trapping and poisoned baits have been used to control pocket gophers (Dingle 1956) and other rodents. Most poisons are potential hazards for other animals, and should be used under the supervision of the Fish and Wildlife Service.

Where deer populations become excessive, their browsing and trampling can be very destructive. In northwestern Montana, effects of deer browsing on planted and natural ponderosa pine seedlings were compared inside and outside of fenced deer exclosure plots (Adams 1951a,b). On the unfenced plots, over half of the planted pines were killed or heavily browsed the first year; more than 80 percent of the trees were dead after 4 years. Browsing also destroyed more than 80 percent of natural seedlings in a similar test. Regulating deer numbers by hunting, or increasing the amount of other browse available are possible methods of reducing deer damage. In plantations where intensive treatment is possible, the coating of leaders with chemical repellents has provided good protection from deer for 1 year in the Southwest (Heidmann 1963).

The damage to regeneration by sheep and cattle is due mostly to trampling. In an early study (Sparhawk 1918) mortality from grazing animals varied from 0.7 percent in the 3-1/2- to 4-1/2-foot high seedling class to 59.2 percent in seedlings less than a year old. Fortunately, damage from grazing stock can be avoided and their exclusion should be part of the management plan until the average tree is 4-1/2 feet high.

Competition.--No other mortality cause is as relentless as the contest among individuals for light, moisture, or nutrients. Moisture is scarce in the growing season on typical ponderosa pine sites, and therefore the more complete and the more enduring the reduction of competition, the greater the survival of seedlings. After the seedlings become established, competition develops between trees of the new stand. This can be controlled by management through regulation of the stocking density of the stand. Stocking density affects the growth of the trees as well as their survival, health, and vigor. Desirable stocking for different management goals is determined by complex biological and economic considerations. Accumulated evidence indicates a rather wide range of densities within which total stand volume growth is nearly constant. Thus, forest managers have considerable latitude in managing individual stands according to their needs.

Some degree of stocking control is needed in ponderosa pine stands of the northern Rockies, even though the actual stocking favored may vary. Control of the growing stock through management will reduce the volume of wood lost through competition in overstocked stands and advance the date when trees reach merchantable size.

Summary

This paper summarizes present information on natural and artificial regeneration of ponderosa pine in the territory served by the Intermountain Forest and Range Experiment Station. In this area, ponderosa pine grows under a wide range of conditions typified by varying rainfall, high temperatures, and low humidities during the growing season, mountainous topography, and great diversity of soil types and depths. It is a climax or seral species in 11 habitat types, ranging from warm and dry to cool and moist.

The ease with which ponderosa pine can be regenerated varies with conditions; therefore, no single regenerative technique can be employed with success everywhere. Some generalities, however, apply in varying degrees to ponderosa pine stands throughout the Intermountain Station territory.

Some kind of site preparation is necessary to establish either natural or artificial regeneration. Because soil moisture is a critical factor in seedling establishment, competition from other vegetation must be effectively reduced. Techniques include hand scalping, mulching, use of herbicides or fire, and machine stripping and terracing.

Planting has become an established method of regenerating brushfields and timber sale areas. Several planting systems are used successfully. Trees may be planted by hand or by machine on well-prepared sites. Seed source, for either direct seeding or planting, must be carefully chosen. Seed supply varies widely from year to year.

Direct seeding has never been used as extensively as planting in this region, although some seedings on favorable sites have been successful. The major factors in successful seeding are good site preparation, and protection from seed-eating rodents and birds.

In planting, healthy nursery stock and care in handling and field planting are essential.

Successful natural regeneration of ponderosa pine depends on a combination of abundant seed supply and minimum competing vegetation. Good cone crops occur irregularly so site preparation may have to be delayed to coincide with a heavy seed crop. In years of heavy seed crops, several high forest methods of reproduction cutting have been shown to produce sufficient seed for regeneration; seed-tree, shelterwood, group selection, and stem selection cutting have been tested. These methods are successful to varying degrees, depending partly on the habitat type of the stand location.

Numerous natural forces cause mortality of trees of different ages. Squirrels, chipmunks, and mice are responsible for the greatest losses in seed and can harvest most of the seed crop in light and medium years. The chief cause of seedling loss during the period of establishment and after germination or planting is drought, which often accounts for more than half of total mortality in the first 3 years. These losses can be reduced by rodent control measures, adequate site preparation, or timely weedings and thinnings. Other causes of mortality, such as fire, insects, diseases, and animals, are more sporadic. Control of these forces requires regular surveillance and prompt action when required.

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FOILES, MARVIN W., and JAMES D. CURTIS

1973. Regeneration of ponderosa pine in the northern Rocky Mountain-Intermountain Region. USDA For. Serv. Res. Pap. INT-145, 44 p., illus. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Present knowledge of natural and artificial regeneration of ponderosa pine in the northern Rocky Mountains and Intermountain West is summarized. Some regeneration techniques that have been tested in this territory are described. Planting is the most successful method of artiticial regeneration; direct seeding is sometimes used. Several cutting methods may provide for natural regeneration if properly applied.

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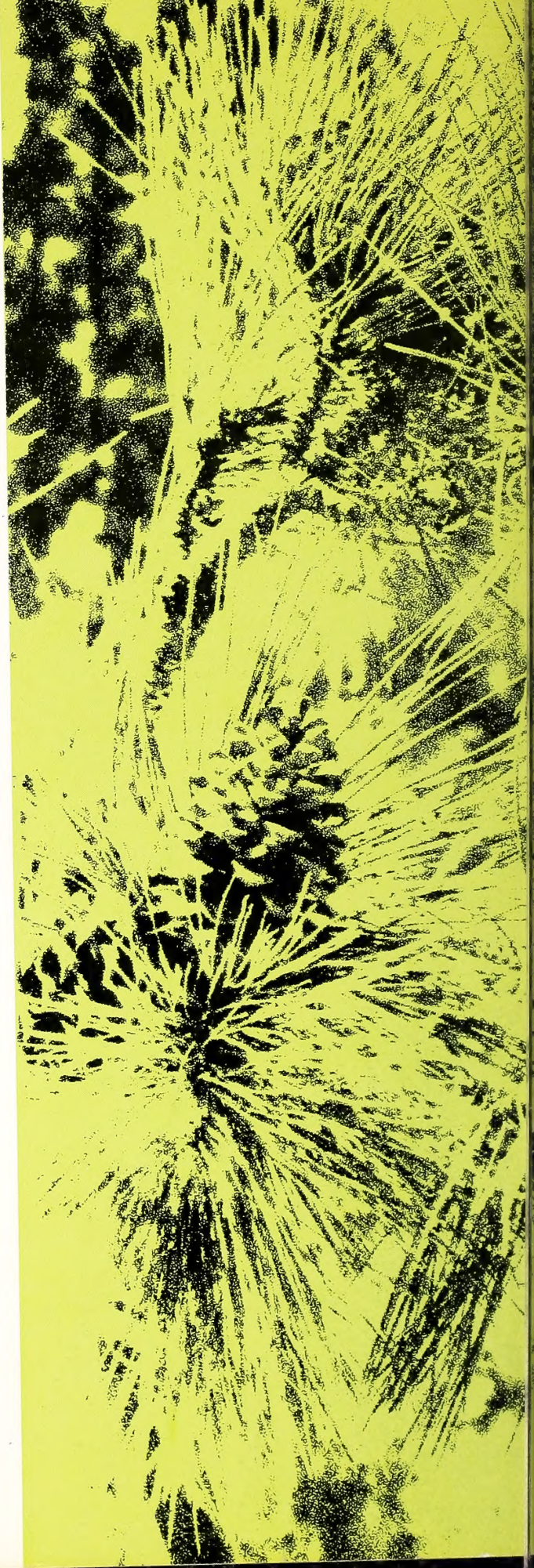

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